

PATENT APPLICATION

Attorney Docket: 54140

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Tzannes, et al.
Serial No.: 08/804.909
Filed: 2/25/97
For: MULTI-CARRIER
TRANSMISSION SYSTEM
UTILIZING CHANNELS OF
DIFFERENT BANDWIDTH

PETITION UNDER 37 C.F.R. 1.47

Hon. Commissioner of Patents
and Trademarks
Washington, D.C. 20231

Sir:

This is a petition to allow Aware, Inc. to execute the Declaration for Patent Application in the above identified on behalf of Mr. Stautner and Mr. Jayasimha.

1. Harm to Aware if this petition is not granted.

The above identified patent application is a continuation-in-part of U.S. Patent Application Serial Number 08/307,331 which is a divisional application of Serial Number 07/948,147 on which each of these inventors is a named inventor. If this petition is not granted, Aware, Inc. will suffer irreparable harm by losing the benefit of the filing date of September 21, 1992 of the 07/948,147 application.

2. Aware's Proprietary Interest

These inventors have assigned their entire right and interest in the subject matter of 07/948,147 to Aware, Inc. These assignments are recorded at Reel/Frame 6332/0751 and 6299/914. I have interviewed inventors Tzannes and Heller and, on information and

belief based on these interviews, any new matter added to this application that was not disclosed in 07/948,147 was invented by inventors Tzannes and Heller.

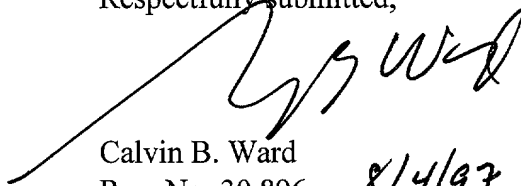
In addition, Mr. Stautner and Mr. Jayasimha were further under a duty to assign any inventions made by them to Aware, Inc. Copies of the employment agreements of these inventors are attached hereto as Exhibits C and D.

3. Aware has made a bona fide attempt to comply obtain the signatures of Mr. Stautner and Mr. Jayasimha on the Declaration.

I have tried to locate Mr. Jayasimha to seek his signature on a Declaration for Patent Application in the above identified patent application. In particular, I caused a letter to be sent by Express mail (EI497254179US) on July 15, 1997 to his last known address. This letter was returned as undeliverable. A copy of this letter is attached hereto as Exhibit A.

Similarly, I have tried to locate Mr. Stautner to seek his signature on a Declaration for Patent Application in the above identified patent application. In particular, I caused a letter to be sent by Express mail (EI497254182US) on July 15, 1997 to his last known address. This letter was returned as undeliverable. A copy of this letter is attached hereto as Exhibit B.

Respectfully submitted,


Calvin B. Ward
Reg. No.:30,896

8/4/97

18 Crow Canyon Rd, #305
San Ramon, CA 94583
510-855-0413
510-855-9214(FAX)

EXHIBIT A

THE LAW OFFICES OF
Dr. CALVIN B. WARD

18 Crow Canyon Court, Suite 305
San Ramon, CA 94583

Telephone (510) 855-0413
FAX (510) 855-9214
Email 74757.2701@compuserve.com

July 15, 1997

Sriram Jayasimha
2602 Stearns Hill Rd., Apt 1020
Waltham, MA 02154

EI497254179US

Re: Multi-Carrier Transmission System Utilizing Channels of Different Bandwidth

Our File No.:54140

Dear Sriram,

Aware has filed a continuation-in-part application based on U.S. Patent application 08/307,331 on which you are listed as an inventor. Accordingly, you have been named as an inventor on the continuation-in-part application. Aware is giving you an opportunity to execute the Declaration and Assignments connected with the continuation-in-part application. If you do not wish to execute these documents, please so advise me as soon as possible. If you are willing to execute the documents, please so advise me, and I will send you a copy of the application and the formal papers. If we do not receive a reply to this letter by August 1, 1997, we will assume that you are not willing to cooperate in the execution of these documents.

If you have any questions about this matter, please call me as soon as possible.

Very truly yours,

Calvin B. Ward

Calvin B. Ward

SK

EXHIBIT B

THE LAW OFFICES OF
Dr. CALVIN B. WARD

18 Crow Canyon Court, Suite 305
San Ramon, CA 94583

Telephone (510) 855-0413
FAX (510) 855-9214
Email 74757.2701@compuserve.com

July 15, 1997

EI497254182US

Mr. John Stautner
18 Tennyson Road
Wellesley, MA 02181

Re: Multi-Carrier Transmission System Utilizing Channels of Different Bandwidth

Our File No.: 54140

Dear Mr. Stautner,

Aware has filed a continuation-in-part application based on U.S. Patent application 08/307,331 on which you are listed as an inventor. Accordingly, you have been named as an inventor on the continuation-in-part application. Aware is giving you an opportunity to execute the Declaration and Assignments connected with the continuation-in-part application. If you do not wish to execute these documents, please so advise me as soon as possible. If you are willing to execute the documents, please so advise me, and I will send you a copy of the application and the formal papers. If we do not receive a reply to this letter by August 1, 1997, we will assume that you are not willing to cooperate in the execution of these documents.

If you have any questions about this matter, please call me as soon as possible.

Very truly yours,

Calvin B. Ward
Calvin B. Ward SK

EXHIBIT C

**NON-DISCLOSURE, NON-COMPETITION,
AND INTELLECTUAL PROPERTY AGREEMENT.**

THIS AGREEMENT is between Aware, Inc., a Massachusetts corporation with principal offices at One Memorial Drive, Cambridge, MA 02142 (hereinafter "the Company"), and Sriram Jayasinha (hereinafter "Consultant").

WHEREAS, Consultant has been or is being engaged by the Company to work in the position of intermittent consultant to develop software, because of Consultant's intellectual character and extraordinary ability; and

WHEREAS, said engagement is of a confidential nature involving duties that require the Company to impose on Consultant the highest trust and confidence;

NOW, THEREFORE, in consideration of the initiation or the continuation of engagement, of other good and valuable consideration received by Consultant, receipt of which is hereby acknowledged, and of the mutual promises and covenants contained herein, the parties agree as follows:

1. Definitions

a. Subsidiary

As used herein, the term "Subsidiary" means any corporation in which not less than 50% of the outstanding capital stock granting voting power to elect a majority of its Board of Directors is owned, directly or indirectly, by the Company.

b. Proprietary Information

As used herein, the term "Proprietary Information" refers to any and all information of a confidential, proprietary, or secret nature that is or may be either applicable to, or related in any way to (i) the business, present or future, of the Company or any Subsidiary, of (ii) the research and development or investigations of the Company or of any Subsidiary. Proprietary Information includes, for example and without limitation, trade secrets, processes, formulas, data, know-how, improvements, inventions, techniques, marketing plans and strategies, and information concerning customers or vendors. In particular, Consultant acknowledges that all information related to the Company's solution of differential and integral equations by wavelet-related methods shall be deemed as proprietary information.

c. Inventions

As used herein, the term "Inventions" refers to all inventions, computer programs, discoveries, improvements, trade secrets, formulas, techniques, processes, confidential information, and know-how, whether or not patentable and whether or not reduced to practice, conceived or learned by Consultant during the period of engagement, either alone or jointly with others, which relate to or result from the actual or anticipated business, work, research, or investigations of the Company, or any Subsidiary, or which result, to any extent, from use of the Company's premises or property.

2. Engagement

(a) The Company has hired Consultant to work on such tasks as shall be specified from time to time. This engagement is not for any particular period, and may be terminated, with or without cause at any time.

(b) Consultant acknowledges that, as a part of his or her engagement, Consultant is expected to create inventions and/or ideas of value for the Company.

3. Confidential Information of Others

If the Consultant possesses any confidential information or documents belonging to others, Consultant will not use, disclose to the Company, or induce the Company to use, any such information or documents during his or her engagement. Consultant represents that his or her engagement will not require Consultant to violate any obligation to or confidence with another.

4. Proprietary Information to be Kept In Confidence

Consultant acknowledges that the Proprietary Information is a special, valuable, and unique asset of the Company, and Consultant agrees at all times during the period of engagement and thereafter to keep in confidence and trust all Proprietary Information. Consultant agrees that during the period of engagement and thereafter Consultant will not directly or indirectly use the Proprietary Information other than in the course of performing duties as an Consultant of the Company, nor will Consultant directly or indirectly disclose any Proprietary Information or any information relating thereto to any person or entity, except in the course of performing duties as an Consultant of the Company and with the written consent of the Company. Consultant will abide by the Company's policies and regulations, as established and revised from time to time, for the protection of its Proprietary Information.

5. Other Engagement

Consultant agrees that during the period of engagement by the Company, and for one year thereafter, he will not directly or indirectly engage in any engagement, consulting, or activity involving the solution of differential and integral equations by wavelet methods other than for the Company which would conflict with Consultant's obligations to the Company.

6. Return of Materials at Termination

In the event of termination of engagement with the Company for any reason, Consultant will promptly deliver to the Company, or any Subsidiary designated by it, all Company documents, data, records, and other information, and Consultant shall not take any documents or data, or any reproduction or excerpt of any documents or data, containing or pertaining to any Proprietary Information.

7. Disclosure of Inventions to the Company

Consultant agrees promptly to disclose in writing to the Company any and all Inventions. For the purpose of this Agreement, an Invention is deemed to have been made during the period of engagement if, during such period, the invention was conceived or first actually reduced to practice. Consultant further agrees to disclose to the Company in writing and in confidence all patent applications naming Consultant as an inventor which are filed within one year after the termination of engagement with Company.

8. Inventions a Sole Property of Company

Consultant acknowledges and agrees that all the Inventions relating to mutually agreed specific tasks shall be the sole property of the Company or any other entity designated by it, and Consultant hereby assigns to the Company Consultant's entire right and interest in all Inventions. Consultant will not use for his or her own benefit, directly or indirectly, any of said Inventions. The Company or any other entity designated by it shall be the sole owner of all domestic and foreign rights pertaining to the Inventions. Consultant further agrees to assist the Company in every way (at the Company's expense) to obtain and from time to time to enforce patents on the Inventions in any and all countries. To that end, by way of illustration but not limitation, Consultant will testify in any suit or other proceeding involving any of the Inventions, execute all documents that the Company reasonably determines to be necessary or convenient for use in applying for and obtaining patents thereon and enforcing the same, and execute all necessary assignments thereof to the Company or entities designated by it. Consultant's obligation to assist the Company in obtaining and enforcing patents for the Inventions shall continue beyond the engagement

termination, but the Company shall compensate Consultant at your established consulting rate after such termination for time actually spent by Consultant at the Company's request on such assistance.

9. Power of Attorney

Consultant hereby grants to the Company a general power of attorney to file patent applications on Inventions in any country in Consultant's name and to execute any document connected with such a filing or the prosecution of a patent application naming Consultant as an inventor on behalf of Consultant.

10. List of Prior Inventions

All inventions, if any, which Consultant made prior to engagement by the Company which are to be excluded from the scope of his agreement are set forth in Exhibit A attached hereto. Consultant represents and covenants that this is a complete list of all inventions, discoveries, or improvements that have been made by Consultant prior to engagement with the Company.

11. Injunction

Consultant agrees that it would be difficult to measure damage to the Company from any breach by Consultant of the promises set forth in Paragraphs 4, 5, 6, 7, and 8 herein; that injury to the Company from any such breach would be impossible to calculate, and that money damages would therefore be an inadequate remedy for any such breach. Accordingly, Consultant agrees that if Consultant breaches any provision of these Paragraphs, the Company shall be entitled, in addition to all other remedies it may have, to injunctions or other appropriate orders to restrain any such breach by Consultant without showing or proving any actual damage sustained by the Company.

12. General

(a) To the extent that any of the agreements set forth herein, or any word, phrase, clause or sentence thereof, shall be found to be illegal or unenforceable for any reason, such agreement, word, clause, phrase, or sentence shall be modified or deleted in such manner as to make the agreement as modified legal and enforceable under applicable laws, and the balance of the agreements or part thereof shall not be affected thereby, the balance being construed as severable and independent.

(b) This Agreement shall be binding upon Consultant and Consultant's heirs, executors, assigns, and administrators and shall inure to the benefit of the Company, its successors and assigns, and any Subsidiary.

Exhibit D**CONSULTING AGREEMENT**

THIS AGREEMENT is between Aware, Inc., a Massachusetts corporation with principal offices at One Memorial Drive, 4th Floor, Cambridge, MA 02142 (hereinafter "the Company"), and John Stautner, (hereinafter "the Consultant"):

WHEREAS, Consultant has been or is being employed by the Company to work in the Target Area, as defined below, because of Consultant's intellectual character and extraordinary ability in the Target Area; and

WHEREAS, said employment is of a confidential nature involving duties that require the Company to impose on Consultant the highest trust and confidence;

NOW, THEREFORE, in consideration of the initiation or the continuation of employment, and of other good and valuable consideration received by Consultant, receipt of which is hereby acknowledged, and of the mutual promises and covenants contained herein, the parties agree as follows:

1. Definitions**a. Target Area**

The term "Target Area" shall refer to digital systems and methods for coding audio signals such that the coded signals require fewer bits to represent than the uncoded signals. The areas listed in Exhibit A attached hereto are deemed to be outside the Target Area.

b. Wavelets

The term "Wavelets" shall refer to the mathematics and applications of said mathematics related to functions satisfying the recursion relation:

$$F(x) = \sum_i a_i F(mx-i)$$

Where m is an integer and $\{a_i\}$ for $i=1$ to N are complex numbers. Said summation being carried out from 1 to N.

c. Affiliate

As used herein, the term "Affiliate" means (1) any entity in which the Company or any of its stockholders, directors or officers has a direct or indirect ownership interest (other than insubstantial interests in publicly held companies) or (2) any entity which directly or indirectly through one or more intermediaries, controls, is controlled by, or is under common control with the Company. A list of Affiliates and the relevant business activities thereof will be provided to Consultant upon written request by Consultant.

d. Proprietary Information

As used herein, the term "Proprietary Information" refers to any and all information in the Target Area or related to Wavelets of a confidential, proprietary, or secret nature that is or may be either applicable to, or related in any way to (i) the business, present or future, of the Company or any Affiliate, or (ii) the research and development or investigations of the Company or of any Affiliate. Proprietary Information includes, for example and without limitation, trade secrets, processes, formulas, data, know-how, improvements, inventions, techniques, marketing plans and strategies, and information concerning customers or vendors. Notwithstanding the above, the information listed in Exhibit A attached hereto shall not be considered Proprietary Information. The Company agrees to make a determination, upon written request, as to whether any specific information is Proprietary Information within the meaning of this agreement. Should said determination indicate that the information is Proprietary, the Company shall provide Consultant with its reasoning in arriving at that conclusion.

e. Inventions

As used herein, the term "Inventions" refers to all inventions, computer programs, discoveries, improvements, trade secrets, formulas, techniques, processes, confidential information, and know-how, whether or not patentable and whether or not reduced to practice, conceived or learned by Consultant during the period of employment, either alone or jointly with others, which relate to the Target Area or Wavelets or result from the actual or anticipated business, work, research, or investigations of the Company, or any Affiliate, in the Target Area or related to Wavelets, or which result, to any extent, from use of the Company's premises or property. The Company agrees to make a determination, upon written request, as to whether any specific invention, computer program, discovery, etc is an Invention within the meaning of this agreement.

2. Employment

The Company has hired Consultant to work in the Target Area on a project by project basis. Each project and the compensation therefor will be specified in a written project agreement signed by an officer of Company and Consultant. The specific terms of said project agreements shall take precedent over the terms of this agreement to the extent that such specific terms are in conflict with the terms of this agreement. A breach of the specific terms of any project agreement shall not relieve the parties of their duties with respect to the terms of this agreement or other project agreements.

This employment is not for any particular period, and may be terminated, with or without cause at any time.

3. Confidential Information of Others

If the Consultant possesses any confidential information or documents belonging to others, Consultant will not use, disclose to the Company, or induce the Company to

[illegible]

use, any such information or documents during his employment. Consultant represents that his employment will not require Consultant to violate any obligation to or confidence with another.

4. Proprietary Information to be Kept In Confidence

Consultant acknowledges that the Proprietary Information is a special, valuable, and unique asset of the Company, and Consultant agrees at all times during the period of employment and thereafter to keep in confidence and trust all Proprietary Information. Consultant agrees that during the period of employment and thereafter Consultant will not directly or indirectly use the Proprietary Information other than in the course of performing duties as an Consultant of the Company, nor will Consultant directly or indirectly disclose any Proprietary Information or any information relating thereto to any person or entity, except in the course of performing duties as an Consultant of the Company and with the written consent of the Company. Consultant will abide by the Company's policies and regulations, as established and revised from time to time, for the protection of its Proprietary Information.

Company acknowledges that the information included in Exhibits A and B attached hereto include proprietary information of Consultant. Company agrees to hold such information in confidence and to treat such information with the same degree of care as it treats its own proprietary information.

5. Other Employment

Consultant agrees that during the period of employment by the Company, Consultant will not, without the Company's prior written consent, directly or indirectly engage in any employment, consulting, or activity other than for the Company relating to any line of business in which the Company is now or at such time engaged, or which would otherwise conflict with Consultant's obligations to the Company. The Company acknowledges Consultant's current obligations to as listed in Exhibit B. The Consultant warrants that none of these existing relationships conflicts with Consultants work under this agreement. The Company agrees to make a determination, upon written request, as to whether any specific employment violates this section. The Company will not unreasonably restrict Consultant's other employment under the provisions of this section.

6. Covenant Not to Compete

(a) Without the prior express written consent of the Company, during the period in which Consultant is employed by the Company, Consultant agrees not to directly or indirectly anywhere in the world:

(i) engage or participate (with or without compensation) in any commercial research or commercial project which is the same or substantially similar (in purpose, objective, or result) to any research or project in which the Company or its Affiliates engaged, participated or researched during the employment period; or

(ii) during Consultant's employment or for a period of one year thereafter, recruit or otherwise solicit or induce any employees of the Company or any of its Affiliates to terminate their employment with, or otherwise cease their

relationship with the Company or any of its Affiliates.

(b) The restrictions against competition set forth in Paragraph 6(a) are considered by the parties to be reasonable for the purposes of protecting the business of the Company. However, if any such restriction is found by a court of competent jurisdiction to be unenforceable because of its temporal extent, geographic extent, or breath of activities, it shall be interpreted to extend only over the maximum period of time, range of activities, or geographic areas as to which it may be enforced.

7. Return of Materials at Termination

At the termination of employment with the Company for any reason, Consultant will promptly deliver to the Company, or any Affiliate designated by it, all Company documents, data, records, and other information, and Consultant shall not take any documents or data, or any reproduction or excerpt of any documents or data, containing or pertaining to any Proprietary Information.

8. Disclosure of Inventions to the Company

Consultant agrees promptly to disclose in writing to the Company any and all Inventions related to the Target Area or Wavelets. For the purpose of this Agreement, an Invention is deemed to have been made during the period of employment if, during such period, the invention was conceived or first actually reduced to practice. Consultant further agrees to disclose to the Company in writing and in confidence all patent applications naming Consultant as an inventor which are filed within one year after the termination of employment with Company.

9. Inventions as Sole Property of Company

Consultant acknowledges and agrees that all the Inventions in the Target Area or Wavelets shall be the sole property of the Company or any other entity designated by it, and Consultant hereby assigns to the Company Consultant's entire right and interest in all such Inventions. Consultant will not use for his own benefit, directly or indirectly, any of said Inventions. The Company or any other entity designated by it shall be the sole owner of all domestic and foreign rights pertaining to said Inventions. Consultant further agrees to assist the Company in every way (at the Company's expense) to obtain and from time to time to enforce patents on said Inventions in any and all countries. To that end, by way of illustration but not limitation, Consultant will testify in any suit or other proceeding involving any of said Inventions, execute all documents that the Company reasonably determines to be necessary or convenient for use in applying for and obtaining patents thereon and enforcing the same, and execute all necessary assignments thereof to the Company or entities designated by it. Consultant's obligation to assist the Company in obtaining and enforcing patents for said Inventions shall continue beyond the employment termination, but the Company shall compensate Consultant at Consultant's established consulting rate after such termination for time actually spent by Consultant at the Company's request on such assistance.

10. Power of Attorney

Consultant hereby grants to the Company a general power of attorney to file patent applications on Inventions in any country in Consultant's name and to execute any document connected with such a filing or the prosecution of a patent application naming

Consultant as an inventor on behalf of Consultant.

11. List of Prior Inventions

All inventions, if any, which Consultant made in the Target Area or Wavelets prior to employment by the Company which are to be excluded from the scope of this Agreement are set forth in Exhibit A attached hereto. Consultant represents and covenants that this is a complete list of all inventions, discoveries, or improvements relating to the Company's business that have been made by Consultant prior to employment with the Company.

12. Right to License Technology

Should Company terminate its activities in the Target Area, Company agrees to provide a license to the inventions produced by Consultant under this agreement. The terms of said license shall be negotiated in good faith in the event Company terminates its activities in the Target Area. Company will be deemed to have terminated its activities in the Target Area if it has suspended all research and development activities in the Target Area for a period of three years and has no outstanding license agreements with other parties in the Target Area.

13. Injunction

Consultant agrees that it would be difficult to measure damage to the Company from any breach by Consultant of the promises set forth in Paragraphs 3, 4, 5, 6, and 7 herein; that injury to the Company from any such breach would be impossible to calculate, and that money damages would therefore be an inadequate remedy for any such breach. Accordingly, Consultant agrees that if Consultant breaches any provision of these Paragraphs, the Company shall be entitled, in addition to all other remedies it may have, to injunctions or other appropriate orders to restrain any such breach by Consultant without showing or proving any actual damage sustained by the Company.

14. Arbitration

Any controversy or claim arising out of or relating to this contract, or the breach thereof, shall be settled by arbitration in accordance with the Arbitration Rules of the American Arbitration Association, and judgment upon the award rendered by the Arbitrator(s) may be entered in any Court having jurisdiction thereof.

15. General

(a) To the extent that any of the agreements set forth herein, or any word, phrase, clause or sentence thereof, shall be found to be illegal or unenforceable for any reason, such agreement, word, clause, phrase, or sentence shall be modified or deleted in such manner as to make the agreement as modified legal and enforceable under applicable laws, and the balance of the agreements or part thereof shall not be affected thereby, the balance being construed as severable and independent.

(b) This Agreement shall be binding upon Consultant and Consultant's heirs, executors, assigns, and administrators and shall inure to the benefit of the Company, its successors and assigns, and any Affiliate.

(c) This Agreement shall be governed by the laws of the State of Cali-

fornia, which state shall have jurisdiction of the subject matter hereof.

(d) This Agreement may be signed in two counterparts, each of which shall be deemed an original and that together shall constitute one instrument.

(e) The use of the singular in this Agreement includes the plural, as appropriate.

(f) This Agreement represents the entire agreement between Consultant and the Company with respect to the subject matter hereof, superseding all previous oral or written communications, representations, or agreements. This Agreement may be modified only by a duly authorized representative of the Company and said modification must be executed in writing.

Aware

Dated: 26 November 1990

By 
(Signature)

Charles S. SMITH
(Typed or Printed Name)

Consultant

Dated: 

Nov. 26, 1990
(Signature)

JOHN P. STANTNER
(Typed or Printed Name)

EXHIBIT A
LIST OF CONSULTANT'S INVENTIONS AND INFORMATION TO BE
EXCLUDED FROM PROPRIETARY INFORMATION

List each invention, if any, related to the Company's business by title and with a brief summary. State when made and conceived and whether or not a patent has been applied for. Do not list any confidential information.

265220" 60540880

EXHIBIT B**LIST OF OTHER ACTIVITIES IN WHICH CONSULTANT IS ENGAGING DURING THE COURSE OF THIS AGREEMENT**

1. Research on the Following Algorithms:

a. **CROSS-CHANNEL ANALYSIS**

For this description, a frame of audio consists of two or more channels of sampled audio data. For example, N left channel samples and N right samples of a sampled stereo audio signal would comprise a frame with two blocks of length N. The sampled audio signals are analyzed a block at a time to construct an encoded data set describing those samples.

Compute the signals

$$y_l = \sum_k (w_{lk} x_k[n-d_{lk}])$$

where k is the block index in the frame, and l is an analysis index, and the w's are integer weights. The d's are delays with values from zero samples and up. Samples from the previous frame(s) must still be available to compute the y's. Assume there are K channels, and therefore K blocks in the frame. Pick K signals from the set of $y_l[n]$ for the frame such that the K signals chosen have the smallest maximum absolute value. The signals chosen are then packed to the word size determined by the maximum absolute value. This packed data and the K chosen indices of l are formatted and transmitted or stored.

b. **CROSS-CHANNEL SYNTHESIS**

The original sampled signals x_k may be exactly reconstructed from the system of K equations given by (1). Consider, for example, resynthesis of signal $w_{lk} x_k[n]$ shown below. The values are determined by the signals $y_l[n]$ plus integer weights of previous samples from the other channels in the frame. Of course, solution for any particular set of l's is done generally by considering all the K equations for each sample value n in the frame.

$$w_{lk} x_k[n] = y_l[n] - \sum_{k \neq k} (w_{lk} x_k[n-d_{lk}])$$

The samples $x_k[n]$ can be recovered exactly since w_{lk} is integer (as are all w's)

c. **CROSS-CHANNEL ALGORITHMS WITH OTHER ALGORITHMS**

The cross-channel algorithm may be combined with other reduction algorithms. For example, it can be used to pre-process a multi-channel audio signal prior to further lossless processing by a digital filter array algorithm. It can be used to process two or more channels at each particular frequency in a multi-band analysis, so that similar bands are compared with each other and multiplexed. For that matter, it may even be useful within a single channel's multi-band analysis, where the demodulated outputs might be treated as individual channels

for the algorithm to operate on. The algorithm may also be combined with commonly known entropy coders such as Huffman and variable length codes.

Note also the algorithm representation of equation 1 may be further generalized to compute the signals given by

$$y_l[n] = \sum_k (w_{lk} x_k[n-d_{lk}]) + \sum_{ij} (u_{ij} y_{ij}[n-D_{ij}])$$

for integer weights u and sample delays D , which may be used in the same manner as described above.

d. IMAGE COMPRESSION USING N-DIMENSIONAL DIGITAL FILTER ARRAY

The digital filter array algorithm is a lossless algorithm which has been applied to audio data compression and has been described in generally in publications (see list). The basic principles may also be applied to image processing, where the filter operate in two dimensions (single image or three dimensions (motion sequence)).

ANALYSIS

A family of two-dimensional filters is defined which may be addressed by an index. The coefficients at each filter location (x, y) are integer values. The image may be partitioned into sub-images or processed whole. For each image partitions, filter the image by each of the filters in the family, and compute the values of the maximum absolute value of the output. the filtered output and filter index corresponding to the output with the smallest maximum absolute value is selected. This output is packed to the minimum word size requirement and may further be coded using entropy coding methods such as Huffman coding or variable length codes. The encoded data is stored or transmitted.

This approach may be further extended to three-dimensional processing for motion sequence, where the filter family consist of three dimensional filters with integer coefficients at each filter location (x, y, t) .

SYNTHESIS

Synthesis is accomplished by running the encoded data through the inverse filter as specified by the stored or transmitted filter index for the given image partition. Reconstruction is exact since all filter coefficients are integers and there are no round-off errors.

The requirement for image reconstruction starting at an arbitrary partition, or for motion sequence reconstruction starting arbitrary frame, may require that certain initial values are stored or transmitted as well for initialization of the filters during synthesis.

Further data compression may be achieved by allowing lossless operation. This is done by scaling and quantizing the signal prior to the lossless

**Multi-Carrier Transmission System Utilizing Channels of Different Bandwidth**

This application is a Continuation-in-Part of U.S. Patent Application 08/307,331 filed

5 9/16/94.

Field of the Invention

10 The present invention relates to data transmission systems, and more particularly, to an improved multi-carrier transmission system.

Background of the Invention

15 In prior art multi-carrier systems, a communication path having a fixed bandwidth is divided into a number of sub-bands having different frequencies. The width of the sub-bands is chosen to be the same for all sub-bands and small enough to allow the distortion in each sub-band to be modeled by a single attenuation and phase shift for the band. If the noise level in each band is known, the volume of data sent in each band may be maximized for any given bit error rate by choosing a symbol set for each channel having the maximum number of symbols
20 consistent with the available signal-to-noise ratio of the channel. By using each sub-band at its maximum capacity, the amount of data that can be transmitted in the communication path for a given error rate is maximized.

25 For example, consider a system in which one of the sub-channels has a signal-to-noise ratio which allows at least 16 digital levels to be distinguished from one another with an acceptable error rate. In this case, a symbol set having 16 possible signal values is chosen. If the incoming data stream is binary, each consecutive group of 4 bits is used to compute the corresponding symbol value which is then sent on the communication channel in the sub-band in question.

5. Digital Multimedia Associates

Ongoing research and development to build a base of software and digital signal processing components for sale by Digital Multimedia Associates into the multimedia market. This includes market research and development of technical specifications for a corporate video computer; research and development of audio reverberation and spatial positioning algorithms; real-time software and signal processing components (not data compression); integration of off-the-shelf components into computer platforms.

Audio Compression Related: licensing and porting of Compusone CSX audio compression algorithms; Extensions to the CompuSonics CSX audio algorithm (described above).

In digitally implemented multi-carrier systems, the actual synthesis of the signal representing the sum of the various modulated carriers is carried out via a mathematical transformation that generates a sequence of numbers that represents the amplitude of the signal as function of time. For example, a sum signal may be generated by applying an inverse Fourier transformation to a data vector generated from the symbols to be transmitted in the next time interval. Similarly, the symbols are recovered at the receiver using the corresponding inverse transformation.

The computational workload inherent in synthesizing and analyzing the multi-carrier signal is related to the number of sub-bands. For example, if Fourier transforms are utilized, the workload is of order $N \log N$ where N is the number of sub-bands. Similar relationships exist for other transforms. Hence, it is advantageous to minimize the number of sub-bands.

There are two factors that determine the number of sub-bands in prior art systems. First, the prior art systems utilize a uniform bandwidth. Hence, the number of sub-bands is at least as great as the total bandwidth available for transmission divided by the bandwidth of the smallest sub-band. The size of the smallest sub-band is determined by need to characterize each channel by a single attenuation and phase shift. Thus, the sub-band having the most rapidly varying distortion sets the number of sub-bands and the computational workload in the case in which white noise is the primary contributor to the signal-to-noise ratio.

In systems in which the major source of interference is narrow band interference, the minimum sub-band is set with reference to the narrowest sub-band that must be removed from the communication channel to avoid the interference. Consider a communication channel consisting of a twisted pair of wires which is operated at a total communication band which overlaps with the AM broadcast band in frequency. Because of the imperfect shielding of the wires, interference from strong radio stations will be picked up by the twisted pair. Hence, the sub-bands that correspond to these radio signals are not usable. In this case, prior art systems break the communication band into a series of uniform sub-bands in which certain sub-bands are

not used. Ideally, the sub-bands are sufficiently narrow that only the portion of the spectrum that is blocked by a radio signal is lost when a sub-band is marked as being unusable.

Broadly, it is the object of the present invention to provide an improved multi-carrier
5 transmission system.

It is a further object of the present invention to provide a multi-carrier transmission system having a lower computational workload than imposed by systems having bands of equal band-width.

10 These and other objects of the present invention will become apparent to those skilled in the art from the following detailed description of the invention and the accompanying drawings.

Summary of the Invention

The present invention is a communication system for sending a sequence of symbols on a communication link. The system includes a transmitter for placing information indicative of the sequence of symbols on the communication link and a receiver for receiving the information placed on the communication link by the transmitter. The transmitter includes a clock for
20 defining successive frames, each of the frames including M time intervals, where M is an integer greater than 1. A modulator modulates each of the M carrier signals with a signal related to the value of one of the symbols thereby generating a modulated carrier signal corresponding to each of the carrier signals. The modulated carriers are combined into a sum signal which is transmitted on the communication link. The carrier signals include first and second carriers, the
25 first carrier having a different bandwidth than the second carrier. In one embodiment, the modulator includes a tree-structured array of filter banks having M leaf nodes, each of the values related to the symbols forming an input to a corresponding one of the leaf nodes. Each of the nodes includes one of the filter banks. Similarly, the receiver can be constructed of a tree-structured array of sub-band filter banks for converting M time-domain samples received on the
30 communication link to M symbol values.

Brief Description of the Drawings

Figure 1 is a block diagram of a typical prior art multicarrier transceiver.

Figure 2 is a block diagram of a filter bank for performing the time-domain to frequency-domain transformation utilized by the present invention.

Figure 3 is a block diagram of a filter bank for performing the frequency-domain to time-domain transformation utilized by the present invention.

Figure 4 is a schematic view of a second embodiment of a synthesis filter bank that may be used with the present invention to generate a frequency-domain to time-domain transformation.

Figure 5 is a schematic view of a second embodiment of an analysis filter bank that may be used with the present invention to generate a time-domain to frequency-domain transformation.

Detailed Description of the Invention

The manner in which the present invention operates can be more easily understood with reference to Figure 1 which is a block diagram of a typical prior art multi-carrier transceiver 100. Transceiver 100 transmits data on a communication link 113. The input data stream is received by a symbol generator 102 which converts a run of data bits from the input stream into M symbols S_1, S_2, \dots, S_M which are stored in a register 104. The number of possible states for each symbol will depend on the noise levels in the corresponding frequency band on the transmission channel 113 and on the error rate that can be tolerated by the data. For the purposes of the present discussion, it is sufficient to note that each symbol is a number whose absolute

value may vary from 0 to some predetermined upper bound. For example, if a symbol has 16 possible values, this symbol can be used to represent 4 bits in the input data stream.

Transceiver 100 treats the symbols S_i as if they were the amplitude of a signal in a narrow frequency band. Frequency to time-domain transform circuit 106 generates a time-domain signal X_i , for i from 0 to $M-1$, that has the frequency components S_i . The time-domain signals are stored in a shift register 108. The contents of shift register 108 represent, in digital form, the next segment of the signal that is to be actually transmitted over communication link 113. The actual transmission is accomplished by clocking the digital values onto transmission link 113 (possibly after upconversion to radio frequencies) after converting the values to analog voltages using D/A converter 110. Clock 107 provides the timing pulses for the operation. The output of D/A converter 110 is low-pass filtered by filter 112 before being placed on communication link 113.

At the receiving end of transmission link 113, the transmission segment is recovered. The signals received on communication link 113 are low-pass filtered to reduce the effects of high frequency noise transients. The signals are then digitized and shifted into a register 118. When M values have been shifted into register 118, the contents thereof are converted via a time-domain to frequency-domain transform circuit 120 to generate a set of frequency-domain symbols S'_i . This transformation is the inverse of the transformation generated by frequency to time-domain transform 106. It should be noted that communication link 113 will, in general, both attenuate and phase shift the signal represented by the X_i . Hence, the signal values received at low-pass filter 114 and A/D converter 116 will differ from the original signal values. Thus, the contents of shift register 118 will not match the corresponding values from shift register 108. For this reason, the contents of shift register 118 are denoted by X'_i . Similarly, the output of the time to frequency-domain transform will also differ from the original symbols S_i ; hence, the contents of register 122 are denoted by S'_i . Equalizer 124 corrects the S'_i for the attenuation and phase shift resulting from transmission over communication link 113 to recover the original symbols which are stored in buffer 126. In addition, equalizer 124 corrects the symbols for intersymbol interference arising from synchronization errors between the transmitter and

receiver. Finally, the contents of buffer 126 are decoded to regenerate the original data stream by symbol decoder 128.

For efficient design of the equalizer 124 in Figure 1, each subchannel must be sufficiently narrow to allow the distortions in that subchannel to be modeled by a single phase shift and attenuation. Sub-channels must also be sufficiently narrow to assure that a sub-channel that is turned off to prevent interference from narrow band sources does not unduly waste bandwidth beyond that corrupted by the interference source. However, using narrower channels across the transmission band increases both system latency and the computational complexity of the frequency-domain-to-time-domain transformation and its inverse. The present invention is based on the observation that the variation in the attenuation and phase shift as a function of frequency is *greater* at low frequencies than at higher frequencies for communication links consisting of twisted pairs or coaxial cable. Thus, it is advantageous from a computational complexity viewpoint to employ narrower subchannels at the low frequencies and wider subchannels at the higher frequencies in a multicarrier modulation system.

To implement a variable channel width system, a transformation that breaks the available frequency band into sub-bands of differing width is required. Such a transformation may be constructed from a tree configured filter bank. Tree configured filters are known in the audio compression arts. For example, U.S. Patent 5,408,580, which is hereby incorporated by reference, describes the analysis of an audio signal into frequency components representing the audio signal in different frequency bands utilizing such a filter. The frequency bands vary in width such that the lower frequency bands are divided into smaller bands than the higher frequency bands.

Refer now to Figure 2 which illustrates the decomposition of a signal into frequency sub-bands by a tree structured filter 30. Such a filter could be utilized to implement the time-domain to frequency-domain transformation 120 shown in Figure 1. Filter 30 includes two levels of filter banks. The manner in which the filter banks are constructed will be discussed in more detail below. In the example shown in Figure 2, 21 sub-bands are utilized. The decomposition is

carried out in two levels of filters. The first level of filter 30 consists of a filter bank 31 which divides the input signal into eight sub-bands of equal size. The second level subdivides the lowest three frequency bands from filter bank 31 into finer subdivisions. The second level consists of three filter banks 32-34. Filter bank 32 divides the lowest sub-band from filter bank 31 into 8 equal sub-bands. Filter bank 33 and filter bank 34 divide the second and third sub-bands created by filter bank 31 into four sub-bands. The combination of the two levels generates 21 frequency sub-bands. When applying the tree-structured filter bank to multicarrier communications, the analysis filter bank is used to demodulate the received signal. The filter bank performs a time-domain to frequency-domain transformation, converting received signal amplitudes into demodulated symbols for subsequent equalization.

The reverse transformation can be performed by an analogous filter bank such as shown in Figure 3 at 60. Filter 60 provides the frequency-domain to time-domain transformation shown in Figure 1. The reverse transformation also utilizes a two level tree structure. The symbols to be sent on the finer sub-bands are first combined using a first set of synthesis filters shown at 62-64 to provide signals representing three larger sub-bands of the same width as bands 18-22. These "symbols" together with those from bands 18-22 are then combined by synthesis filter 61 to provide the time-domain output signal that is sent on the communication link.

The manner in which the individual filters are constructed is explained in detail in U.S. Patent 5,408,580, and hence will not be discussed in detail here. For the purposes of the present discussion, it is sufficient to note that the filters may be implemented as finite impulse response filters with real filter coefficients. If the synthesis filter generates M coefficients per frame representing the amplitude of the transmitted signal, the filter bank accepts M frequency-domain symbols and generates M time-domain coefficients. However, it should be noted that the M coefficients generated may also depend on symbols received prior to the M frequency-domain symbols of the current frame. Similarly, the analysis filter bank demodulates M frequency-domain symbols from M time-domain received signal values in a given frame, and the resulting M symbols may depend on previous frames of M time-domain signal values processed by the filter bank.

The communication bandwidth may alternatively be broken up into subbands of distinct (nonuniform) bandwidths by means of a single nonuniform filter bank transform. The synthesis filter bank, or frequency-domain-to-time-domain transform for converting symbols into signal values for transmission, is depicted in Figure 4 at 300 for a system having K subchannels. If the subchannels are nonuniform in their bandwidth, distinct subchannels of the filter bank will operate at different upsampling rates, the upsampling rate of the k^{th} subchannel will be denoted by M_k . The upsampling rates are subject to the critical sampling condition

$$\sum_{k=0}^{K-1} \frac{1}{M_k} = 1 \quad (1)$$

Referring to Figure 4, synthesis filter bank 300 generates M_{tot} time-domain samples in each time frame. Here, M_{tot} is the least common multiple of the upsampling rates M_k provided by the upsamplers of which 302 is typical. Define the integers n_k by

$$n_k = M_{\text{tot}} / M_k \quad (2)$$

In each frame of transform processing, n_k symbols, denoted by $s_{k,i}$, are mapped onto the k^{th} subchannel using the sequence, f_k , as the modulating waveform to generate a time domain sequence, x_k , representing the symbols in the k^{th} subchannel, i.e.,

$$x_k[n] = \sum_i s_{k,i} f_k[n - iM_k] \quad (3)$$

Note that symbols from previous frames may contribute to the output of a given frame. Each of the contributions x_k from the K distinct subchannels are added together, as shown at 301, to produce a set of M_{tot} time-domain signal values $x[n]$ from M_{tot} input symbols $s_{k,i}$ during the given frame. The k^{th} subchannel will have a bandwidth that is $1/M_k$ as large as that occupied by the full transmitted signal.

At the receiver, the incoming discrete signal values $x'[n]$ are passed through an analysis filter bank 400, depicted in Figure 5. The received signal values are denoted by x' to emphasize that the samples have been altered by the transmission link. Each filter in this bank has a characteristic downsampling ratio M_k imposed after filtering by an finite impulse response filter, producing a set of M_{tot} output symbols s per frame. A typical filter is shown at 401 with its corresponding downsampler at 402. The output symbol stream for the k^{th} subchannel is given by

$$s'_{k,n} = \sum_i x'[i - nM_k] * H_k[i] \quad (4)$$

Again, input signal values from preceding frames may contribute to the set of symbols output during a given frame.

We require that in an ideal channel, the subchannel waveforms, f_k , together with the receive filters H_k satisfy perfect-reconstruction or near-perfect-reconstruction conditions, with an output symbol stream that is identical (except for a possible delay of an integer number of samples) to the input symbol stream. This is equivalent to the absence of inter-symbol and inter-channel interference upon reconstruction. Methods for the design of such finite-impulse-response filter bank waveforms are known to the art. The reader is referred to J. Li, T. Q. Nguyen, S. Tantarana, "A simple design method for nonuniform multirate filter banks," in *Proc. Asilomar Conf. On Signals, Systems, and Computers*, November, 1994 for a detailed discussion of such filter banks.

Various modifications to the present invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Accordingly, the present invention is to be limited solely by the scope of the following claims.

WHAT IS CLAIMED IS:

1. A communication system for sending a sequence of symbols on a communication link, said communication system comprising a transmitter for placing information indicative of said sequence of symbols on said communication link and a receiver for receiving said information placed on said communication link by said transmitter, said transmitter comprising

a clock for defining successive frames, each said frame comprising M time intervals, where M is an integer greater than 1;

a modulator for modulating each of M carrier signals with a signal related to the value of one of said symbols thereby generating a modulated carrier signal corresponding to each of said carrier signals that is to be modulated and for generating a sum signal comprising a sum of said modulated carrier signals; and

an output circuit for transmitting said sum signal on said communication link, wherein said carrier signals comprise first and second carriers, said first carrier having a different bandwidth than said second carrier.

2. The communication system of Claim 1 wherein said modulator comprises a tree-structured array of filter banks having M leaf nodes, each of said values related to said symbols forming an input to a corresponding one of said leaf nodes, each of said non-leaf nodes comprising one of said filter banks.

3. The communication system of Claim 1 wherein said receiver comprises

an input circuit for receiving and storing M time-domain samples transmitted on said communication link; and

a decoder for recovering said M symbol values, said decoder comprising a tree-structured array of sub-band filter banks, said received M time-domain samples forming the input of the root node of said tree-structured array and said M symbol values being generated by the leaf nodes of said tree-structured array, each said sub-band filter bank comprising a plurality of FIR
5 filters having a common input for receiving an input time-domain signal, each said filter generating an output signal representing a symbol value in a corresponding frequency band.

45 50 55 60 65 70 75 80 85 90 95

Multi-Carrier Transmission System Utilizing Channels of Different Bandwidth

ABSTRACT

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A communication system for sending a sequence of symbols on a communication link. The system includes a transmitter for placing information indicative of the sequence of symbols on the communication link and a receiver for receiving the information placed on the communication link by the transmitter. The transmitter includes a clock for defining successive frames, each of the frames including M time intervals, where M is an integer greater than 1. A modulator modulates each of M carrier signals with a signal related to the value of one of the symbols thereby generating a modulated carrier signal corresponding to each of the carrier signals. The modulated carriers are combined into a sum signal which is transmitted on the communication link. The carrier signals include first and second carriers, the first carrier having a different bandwidth than the second carrier. In one embodiment, the modulator includes a tree-structured array of filter banks having M leaf nodes, each of the values related to the symbols forming an input to a corresponding one of the leaf nodes. Each of the nodes includes one of the filter banks. Similarly, the receiver can be constructed of a tree-structured array of sub-band filter banks for converting M time-domain samples received on the communication link to M symbol values.

**PATENT APPLICATION**
Attorney Docket: 6008/54140**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Applicant(s) or Patentee(s): Tzannes, *et al.*
Application No. or Patent No.: Unassigned
Filed or Issued: Concurrently herewith
For: "MULTI-CARRIER TRANSMISSION SYSTEM UTILIZING
CHANNELS OF DIFFERENT BANDWIDTH"
Group No.: Unassigned
Examiner: Unassigned

VERIFIED STATEMENT (DECLARATION) CLAIMING
SMALL ENTITY STATUS (37 C.F.R. SECTIONS 1.9(f)
AND 1.27(c)) - SMALL BUSINESS CONCERN

I hereby declare that I am an official of the small business concern, and I am empowered to act on behalf of the concern identified below:

NAME OF CONCERN: Aware, Inc.
ADDRESS OF CONCERN: One Oak Park
Bedford, MA 01730-1413

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 C.F.R. Section 121.3-18, and reproduced in 37 C.F.R. Section 1.9(d), for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the above identified invention.

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate (37 C.F.R. Section 1.28(b)).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful

false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

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25 FEB 97

6640880

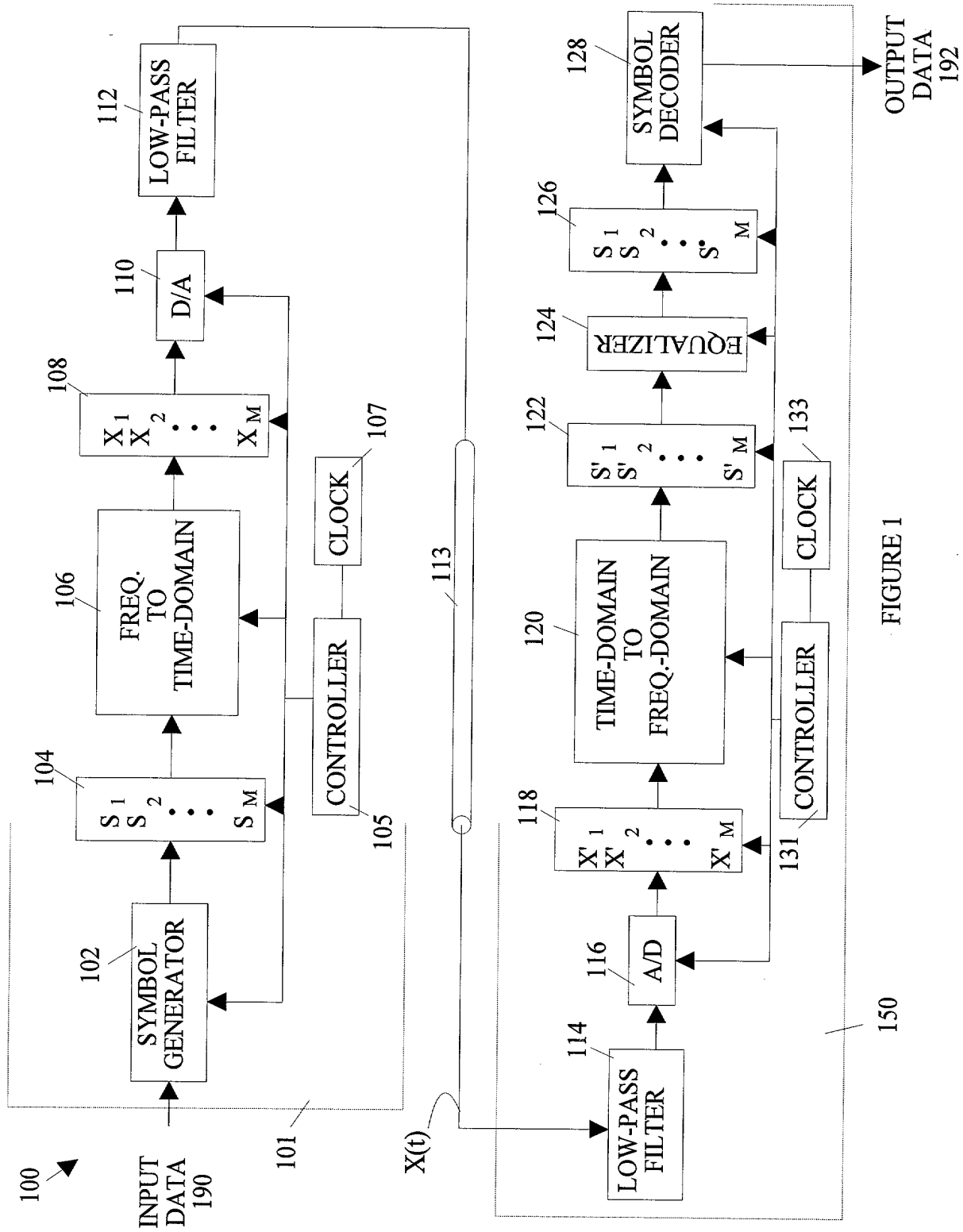


FIGURE 1

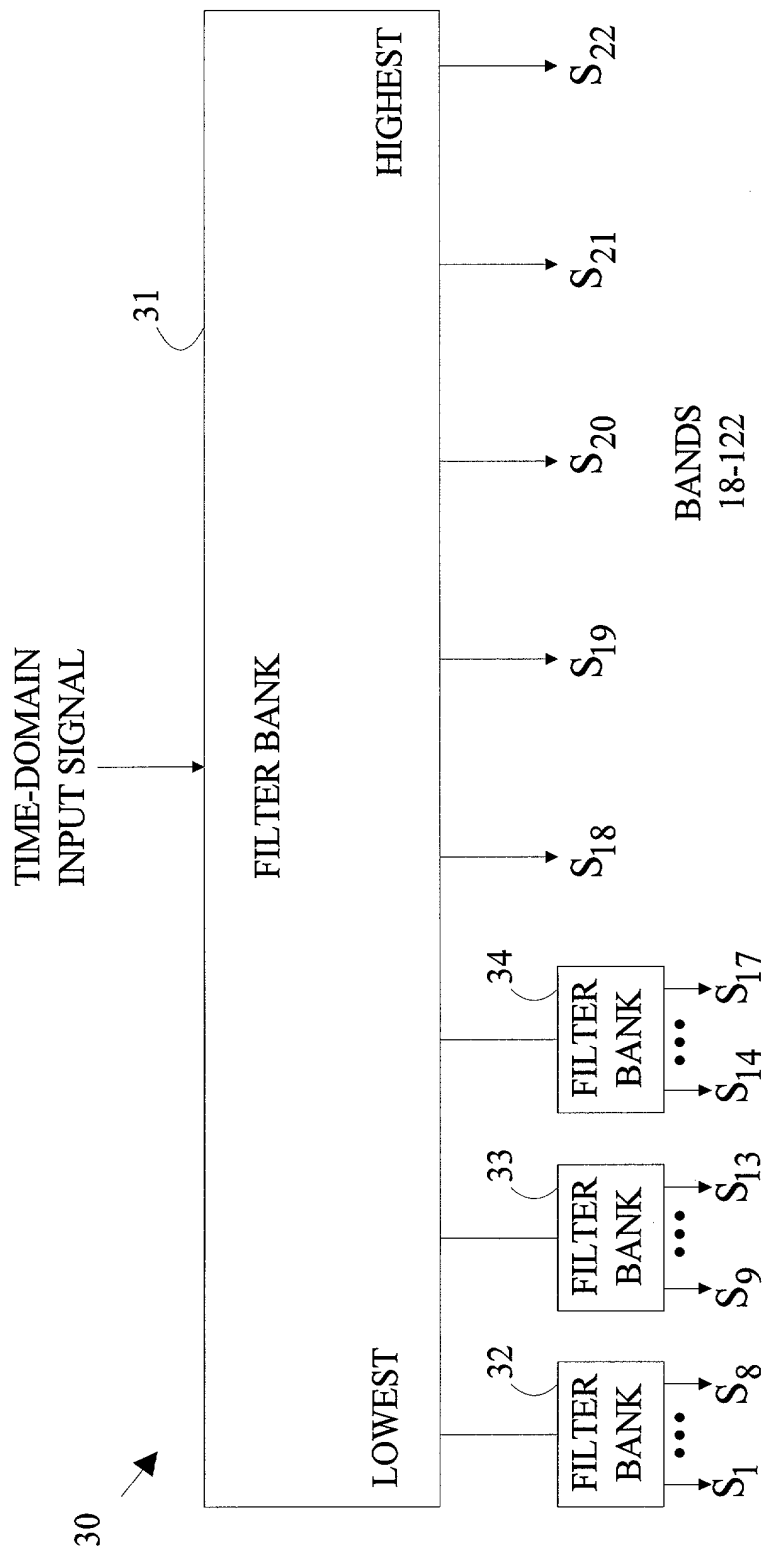


FIGURE 2

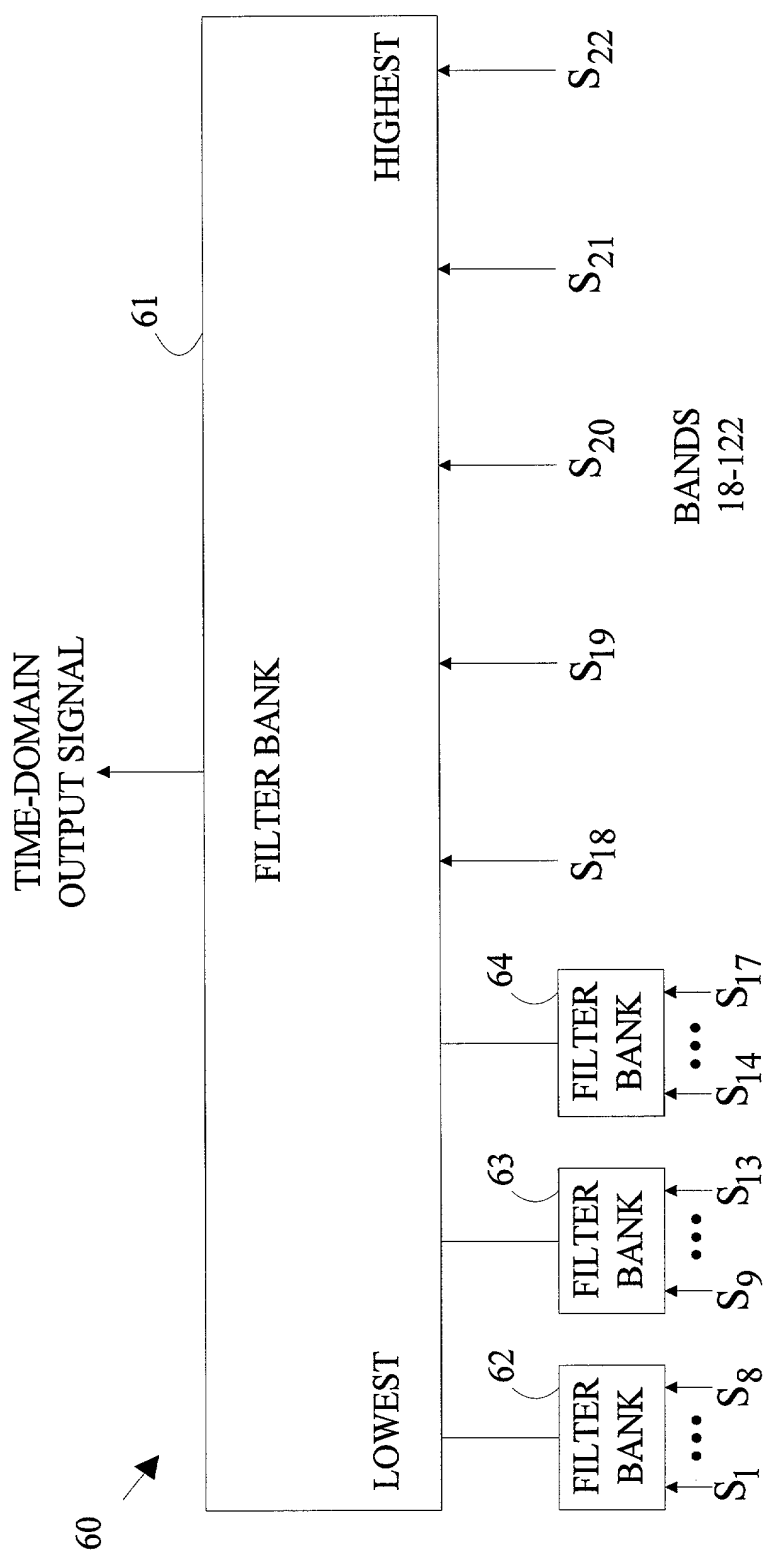


FIGURE 3

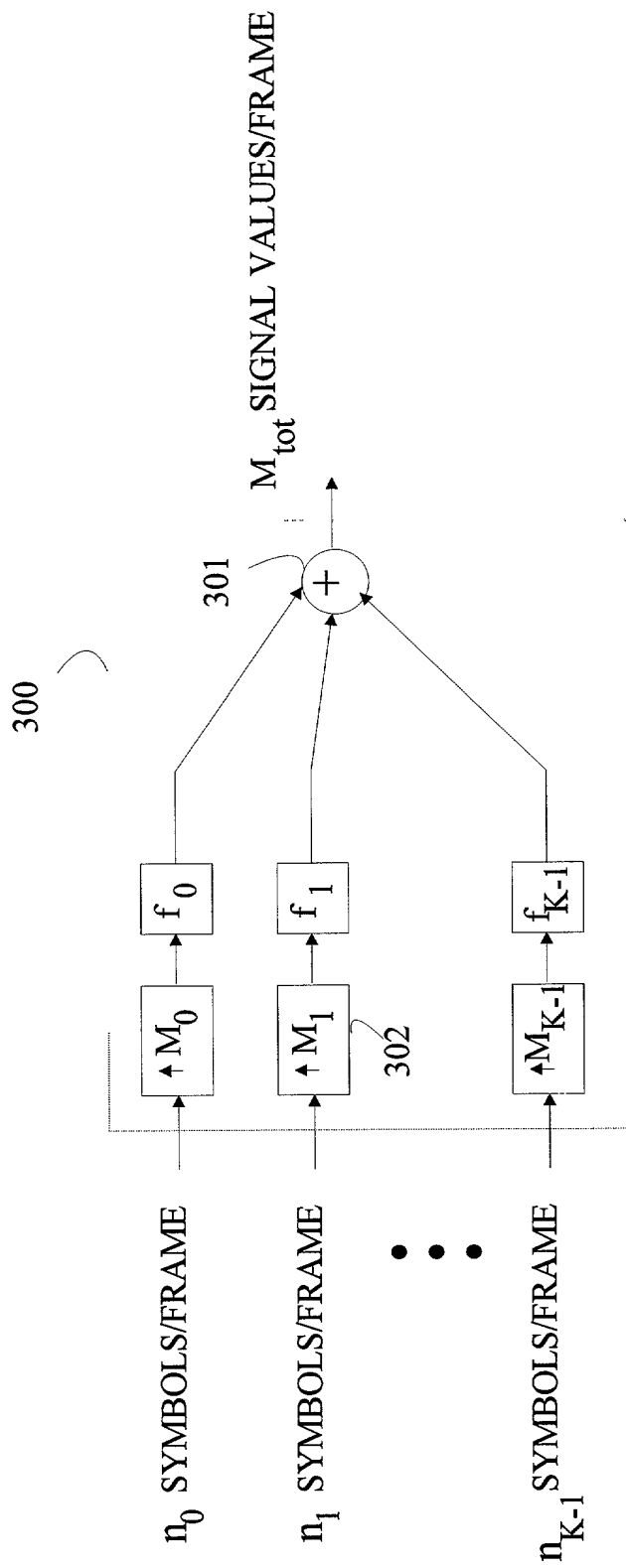


FIGURE 4

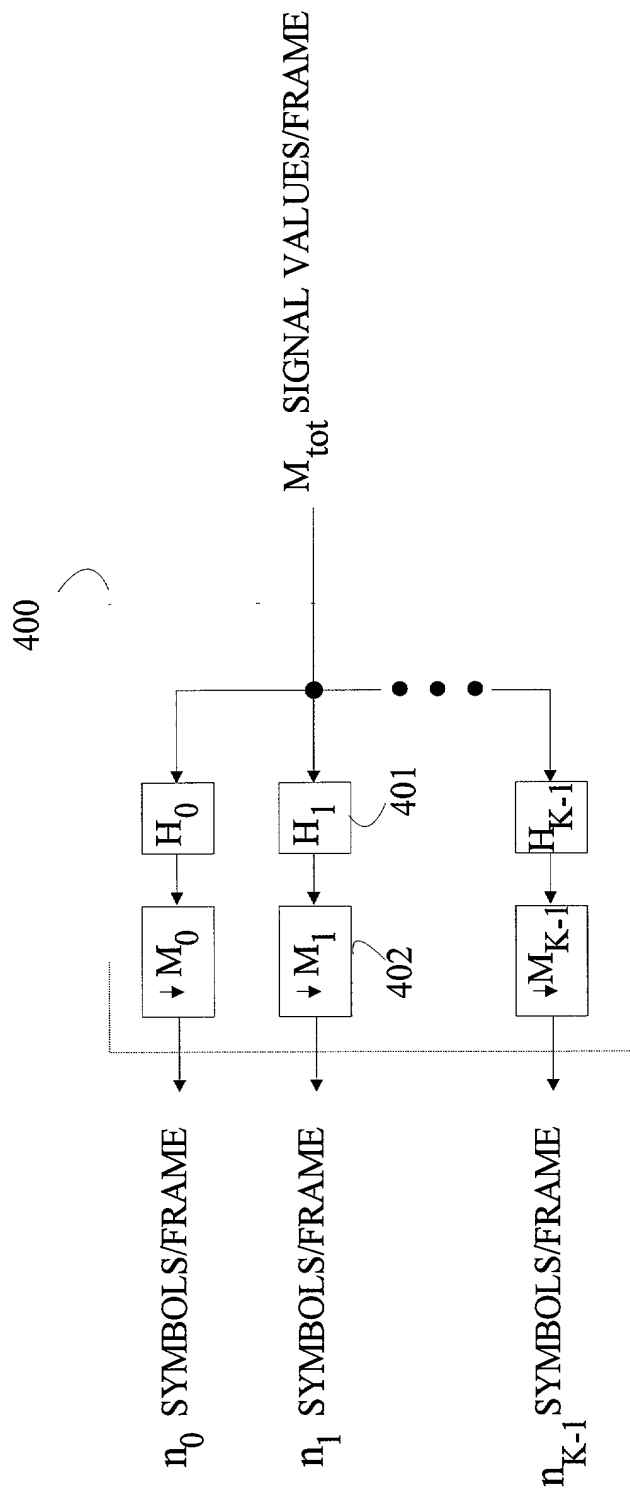


FIGURE 5

DECLARATION FOR PATENT APPLICATION

As a below named inventor, we hereby declare that:

Our residence, post office address and citizenship are as stated below next to our name.

We believe we are the original, first, and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled

**"MULTI-CARRIER TRANSMISSION SYSTEM UTILIZING CHANNELS OF
DIFFERENT BANDWIDTH"**

U.S. Serial Number 08/804,909 filed 2/25/97

We hereby state that we have reviewed and understand the contents of the above-identified specification, including the claims as amended by any amendment referred to above.

We acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

We hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and so identified, and we have also identified below any foreign application for patent or inventor's certificate on this invention filed by us or our legal representatives or assigns and having a filing date before that of the application on which priority is claimed.

<u>Number</u>	<u>Country</u>	<u>Day/Month/Year Filed</u>	<u>Priority Claimed - Yes or No</u>
NONE			

We hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, we acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

<u>Application Serial No.</u>	<u>Filing Date</u>	<u>Status</u>
08/307,331	09/16/94	Allowed

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

We hereby appoint the following attorney, with full power of substitution and revocation, to prosecute this application and to transact all business in the United States Patent and Trademark Office connected therewith and request that all correspondence and telephone calls in respect to this application be directed to Calvin B. Ward, 18 Crow Canyon Court, Suite 305, San Ramon, California 94583, telephone 510-855-0413:

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